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(54) Resolver with leakage flux absorber

(57) A brushless resolver comprising a housing, a rotor rotatably mounted in the housing, a rotary transformer comprising a primary winding carried by the housing and secondary winding on the rotor and operatively associated with the primary winding, a resolver comprising a stator winding carried by the housing and a rotor winding on the rotor and operatively associated with the stator winding, characterized by an electromagnetic flux absorber in the housing between the rotary transformer and the resolver for absorbing leakage electromagnetic flux from the rotary transformer so as to reduce any deviation between the indicated electrical position of the rotor and the actual mechanical position of the rotor during each revolution of the rotor. The flux absorber comprises a copper ring between the rotary transformer primary winding and the resolver stator winding so that the leakage flux creates eddy currents in the ring thereby absorbing or reducing the leakage flux. An additional flux absorber in the form of an element of ferromagnetic material can be provided between the copper ring and the resolver stator winding to absorb stray components of the leakage flux.

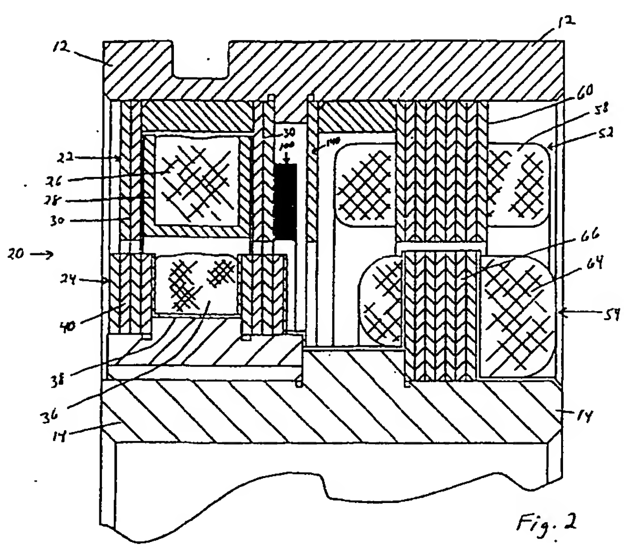

Fig. 2

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Description

Background of the Invention

This invention relates to the art of electrical machines, and more particularly to a new and improved resolver wherein position error due to crosstalk is eliminated.

A basic resolver has a pair of primary windings located at right angles to each other in a rotor and two secondary windings located at right angles to each other in a stator. As the rotor is rotated by a mechanical input, if the rotor winding is excited with a rated input voltage, the output voltage of the one stator winding will be proportional to the cosine of the rotor angle and the output voltage of the other stator winding will be proportional to the sine of the rotor angle.

Thus, the resolver is an analog trigonometric function generator in the form of a rotating transformer which modulates an a.c. excitation signal with the mechanical rotation of the device. The resolver electrical output may be used for position and velocity information. Resolvers are used for moving devices to precise positions with smooth and accurate control, for sensing the position of mechanical devices, for generating speed and position data for robotic, machine tool and aerospace servo applications, and for measuring rotary motion in place of encoders.

In the resolver there is need to transmit the input electrical excitation signal to the rotor windings. Initially this was done using a brush and slip ring sliding contact. Since the brush and slip ring are life-limiting components and can be a source of noise in harsh environments, a brushless resolver was developed wherein a rotary transformer is used to transmit electrical excitation or energy to the rotor.

It has been determined, in accordance with the present invention, that crosstalk between the rotary transformer and the resolver winding in a brushless resolver can give rise to position error in the form of deviation between the indicated electrical position and the actual mechanical position over each revolution of the resolver rotor. It would, therefore, be highly desirable to provide a resolver wherein any deviation between the indicated electrical position of the rotor and the actual mechanical position of the rotor during each resolver revolution is made as small as possible. This must be accomplished by a relatively simple structure which is economical to manufacture.

Summary of the Invention

It is, therefore, an object of at least the preferred embodiment of this invention to provide a new and improved resolver having reduced position error.

It is a more particular object of at least the preferred embodiment of this invention to provide a brushless resolver wherein any deviation between the indicated electrical position of the resolver rotor and the actual mechanical position of the rotor during each resolver revolution is made as small as possible.

It is a further object of at least the preferred embodiment of this invention to reduce crosstalk between the rotary transformer and the resolver winding in a brushless resolver so as to reduce resolver position error arising from such crosstalk.

It is a further object of at least the preferred embodiment of this invention to provide such a resolver which is relatively simple in structure and economical to manufacture.

Accordingly, the present invention provides a brushless resolver comprising:

a) a housing;
b) a rotor rotatably mounted in said housing;
c) a rotary transformer within said housing;
d) a resolver within said housing;
e) electromagnetic flux absorbing means in said housing between said rotary transformer and said resolver for absorbing leakage electromagnetic flux from said rotary transformer so as to reduce any deviation between the indicated electrical position of said rotor and the actual mechanical position of the rotor during each revolution of said rotor.

The flux absorbing means may comprise a conductive element, such as a copper ring or disk, between the rotary transformer primary winding and the resolver stator winding so that the leakage flux creates eddy currents in the ring thereby absorbing or reducing the leakage flux. In addition, an element of ferromagnetic material may be provided between the conductive ring and the resolver stator winding to absorb additional components of the leakage flux.

The foregoing and additional advantages and characterising features of the present invention will become clearly apparent upon a reading of the ensuing detailed description and the claims together with the included drawing wherein:

Brief Description of the Drawing Figures

Fig. 1 is a sectional view of a brushless resolver according to the present invention;

Fig. 2 is an enlarged fragmentary sectional view of a portion of the resolver of Fig. 1;

Fig. 3 is a graph including error characteristics for brushless resolvers according to the prior art and according to the present invention;

Fig. 4 is a graph including error characteristics for a prior art brushless resolver; and

Fig. 5 is a graph including error characteristics and

further illustrating attributes of the resolver according to the present invention.

Detailed Description of the Illustrated Embodiment

Referring first to Fig. 1 there is shown a brushless resolver, generally designated 10, which is of the frameless, hollow-shaft rotor type. Resolver 10 is illustrative of various forms of brushless resolvers to which the present invention is applicable including, for example, resolvers with solid rotor shafts and housed resolvers. Resolver 10 includes a metal or encapsulated housing 12 and an open bore or hollow rotor shaft 14 which is rotatably mounted in housing 12 in a known manner. Rotor 14 is of metal and mounts on a shaft 16 shown in broken lines in Fig. 1 for providing mechanical drive coupling to the mechanical system with which resolver 10 is being used.

Resolver 10, being of the brushless type, includes a rotary transformer generally designated 20 in Fig. 1 including a primary 22 carried by housing 12 and a secondary 24 on rotor 14 and operatively associated with the primary 22. In particular, primary 22 comprises a coil or winding 26, bobbin 28 and laminations 30 of iron or like ferromagnetic material. Primary 22 is fixedly mounted to the inner surface of housing 12 in a known manner and therefore is the stator of rotary transformer 20. The resolver input electrical excitation is applied to primary 22 via input leads 32 whereby coil 26 serves as the primary winding of rotary transformer 20. Secondary 24 similarly comprises a coil 36, bobbin 38 and laminations 40 of iron or like ferromagnetic material. In the illustrative arrangement shown, secondary 24 is fixedly mounted on a sleeve 42 which, in turn, is fixed on rotor 14. Secondary 24 is located on rotor 14 so as to be in flux-linking and thus operative relationship with the transformer primary 22. Thus, coil 36 serves as the secondary winding of rotary transformer 20.

Resolver 10 also includes a resolver stator winding 52 carried by housing 12 and a resolver rotor winding 54 on rotor 14 and operatively associated with stator winding 52. As shown in Fig. 1, the resolver rotor and stator windings 52 and 54, respectively, are located in the resolver 10 so as to be in axially-spaced relation to rotary transformer 20 with respect to the common longitudinal axis of housing 10 and rotor 14. Stator winding 52 comprises the combination of a coil 58 and lamination stack 60 which is fixedly mounted to the inner surface of housing 12 in a known manner. The laminations of stack 60 are of iron or like ferromagnetic material. Rotor winding 54 likewise comprises the combination of a coil 64 and lamination stack 66 which is fixedly mounted to rotor 14 in a known manner. The laminations of stack 66 are of iron or like ferromagnetic material. Winding 54 is located on rotor 14 so as to be in flux-linking and thus operative relationship with resolver stator winding 52.

The secondary 24 of rotary transformer 20 is connected to the resolver rotor winding 54 by leads 70 as shown in Fig. 1. The resolver output electrical signals are present on output leads 72 connected to resolver stator winding 52 as shown in Fig. 1. Thus, winding 52 serves as the output winding of resolver 10.

Resolver 10 as described to this point is typical of prior art brushless resolvers. By way of example, a brushless, frameless resolver is commercially available from Harowe Servo Controls, Inc. of West Chester, Pa. under the model number designation 15BRCX-500. During operation of such prior art brushless resolvers, electromagnetic flux leakage from rotating transformer 20 to resolver stator winding 52 gives rise to a phenomenon known as crosstalk between the transformer and the resolver. In accordance with the present invention it has been determined that such flux leakage can give rise to resolver position error in the form of deviation between the indicated electrical position and the actual mechanical position over each revolution of the resolver rotor. This is illustrated, for example, by curve 80 in the graph of Fig. 3 which shows deviation of the resolver indicated electrical position from the actual mechanical position over one revolution of the resolver rotor shaft. Thus, an electrical error as large as 22 minutes occurs at one point in each cycle of operation of the prior art brushless resolver from which the data for curve 80 was obtained.

The data for curve 80 was obtained by mounting a resolver in a mechanical fixture and coupling its shaft (or rotor assembly, if a frameless device) to a precision mechanical dividing head. The resolver was energized at its rated excitation and the stator output windings were connected to an Angle Position Indicator (API) which electronically converts the signals of the windings to a derived angular position. The dividing head was rotated through one revolution in equal angular increments. At each incremental angular position of the dividing head, the reading of the API was recorded. The difference between the position of the dividing head and the reading of the API was reported as the angular error of the resolver.

The resolver position error problem is illustrated further in Fig. 4 which includes error curves obtained in a manner similar to that for curve 80 and which are error characteristics for a typical prior art resolver. The solid line curve 82 shows the error obtained when excitation is applied directly to the resolver rotor winding, rather than via the rotary transformer. This arrangement can only be tested in the laboratory, but it illustrates the performance which the unit can achieve if the leakage flux from the rotary transformer is not present. In other words, an error of less than about 5 minutes is encountered over a major portion of the resolver cycle. The broken line curve 84 shows the error obtained for the standard resolver connection, where power is applied to the rotary transformer. The dotted line curve 86 represents the absolute difference between these two curves and indicates the magnitude of the effect of the leakage flux from the rotary transformer on the position accuracy of

the device.

In accordance with the present invention, resolver 10 is provided with electromagnetic flux absorbing means in housing 12 between rotary transformer 20 and the resolver for absorbing leakage electromagnetic flux from rotary transformer 20 so as to reduce any deviation between the indicated electrical position of rotor 14 and the actual mechanical position of rotor 14 during each revolution thereof. The flux absorbing means of the present invention provides a dramatic and significant reduction in such deviation as illustrated by the error curve 90 in Fig. 3 for the same resolver used in obtaining data for curve 80 but which resolver is provided with the flux absorbing means of the present invention. As indicated by curve 90, the position error or deviation is reduced significantly to less than 5 minutes over a major portion of each revolution of the resolver rotor.

The electromagnetic flux absorbing means according to the present invention functions to create eddy currents in response to the leakage electromagnetic flux from rotary transformer 20 which eddy currents serve to reduce the leakage flux. Referring now to Fig. 2, the flux absorbing means of the present invention comprises an element 100 of material selected to create eddy currents therein when exposed to electromagnetic flux, in particular a metal electrical conductor preferably of copper. In the resolver shown, element 100 is in the form of a copper ring which is located within housing 12 between the rotary transformer primary winding 22 and the resolver stator winding 52. Ring 100 can be mounted within housing 12 in various ways, and in the resolver shown ring 100 is located with one annular face thereof contacting the outermost one of the transformer primary winding laminations 30 and fixed thereto such as by bonding. Ring 100 is disposed in a plane which is substantially normal to the direction of the leakage electromagnetic flux flowing from rotary transformer 20 toward the resolver winding.

During the operation of resolver 10, leakage flux emitted from rotary transformer 20 flows into copper ring 100 wherein eddy currents are generated in response to the electromagnetic flux which absorbs the flux thereby reducing the amount of leakage flux which can reach the resolver winding 52. Thus the crosstalk between rotary transformer 20 and resolver winding 52 is reduced thereby reducing the position error of resolver 10. Generally speaking, the extent of eddy current generation, which is a result of changing flux with respect to time in a conductor, increases with increasing frequency. Resolvers of the type illustrated herein typically are energized with signals at a frequency which is high enough to provide eddy current generation in ring 100 at a level sufficient to reduce the leakage flux significantly to provide the extent of error reduction illustrated by curve 90 in Fig. 3. By way of example, in an illustrative size 15 brushless resolver, a typical thickness for copper ring 100 would be 0.030 inch. As the excitation frequency decreases, the thickness of ring 100 needs to be increased due to the skin depth effect wherein flux penetrates deeper into the copper material at lower frequency.

The foregoing flux absorption or reduction and consequent position error reduction can be enhanced by providing an additional flux absorbing means in resolver 10. As shown in Fig. 2, the additional flux absorbing means is in the form of an element 140 of ferromagnetic material located between ring 100 and the resolver stator winding 52. Due to the relatively higher permeability of element 140 as compared to the surrounding air, lines of flux tend to be refracted and concentrated in element 140. The conductive ring 100 causes eddy current generation in response to applied leakage flux thereby absorbing or reducing the time-varying component of the leakage flux from rotary transformer 20. Element 140 absorbs any additional components of the leakage flux. In other words, the components of leakage flux absorbed by element 140 are in addition to the principal components of leakage flux absorbed by element 100. In the resolver shown, element 140 is in the form of a thin ring-like plate of ferromagnetic material and can be an additional lamination or laminations similar to either the transformer stator laminations 30 or the resolver stator laminations 60. Satisfactory results, including relatively low position error over each revolution of the resolver rotor, can be obtained with a resolver having only the flux absorbing element 140.

The resolver according to the present invention is illustrated further by the error curves on Fig. 5 which were obtained by a procedure similar to that described above in connection with Figs. 3 and 4. Curve 130 shows the error obtained with direct rotor excitation, i.e. when excitation is applied directly to the resolver rotor winding rather than via the rotary transformer. Curve 132 shows the error obtained when the resolver is excited through the rotary transformer, i.e. the standard resolver connection. Curve 134 shows the error obtained during the standard resolver connection, i.e. excitation through the rotary transformer, and with provision of the flux absorbing ring 100. A significant reduction in position error can be seen in Fig. 5 when comparing curve 134 to curve 132. Curve 136 shows the error obtained during standard resolver electrical connection and with provision of the flux absorbing element 140 alone, and curve 138 shows the error obtained during standard resolver electrical connection when both flux absorbing elements 100 and 140 are provided in the resolver of the present invention. Curve 138 demonstrates that with provision of both flux absorbing elements 100 and 140 according to the present invention, the position error is not greater than about 5 minutes over each revolution of the resolver rotor.

The improvement provided by the present invention is applicable to both single speed and multi-speed resolvers as well as to housed and to frameless resolvers. The improvement of the present invention also is applicable to inside-out resolvers, which are outer rotor de-

vices. In this type of resolver the stator is the inner member and does not rotate; the rotor is the outer member and does rotate. The primary of the rotary transformer is still on the stator, as are the output signal windings (sine and cosine). The flux absorbing elements 100 and 140 are located between the transformer primary and the output (stator) windings.

It is therefore apparent that the present invention accomplishes its intended objects. Resolver 10 of the present invention exhibits a dramatic and significant reduction in the rotor position error caused by leakage flux and crosstalk in prior art resolvers. This is provided by a relatively simple structure which is economical to manufacture.

While an embodiment of the present invention has been described in detail that is done for the purpose of illustration, not limitation.

Claims

1. A brushless resolver comprising:

   a) a housing;
   b) a rotor rotatably mounted in said housing;
   c) a rotary transformer within said housing;
   d) a resolver within said housing;
   e) electromagnetic flux absorbing means in said housing between said rotary transformer and said resolver for absorbing leakage electromagnetic flux from said rotary transformer so as to reduce any deviation between the indicated electrical position of said rotor and the actual mechanical position of the rotor during each revolution of said rotor.

2. A resolver according to Claim 1, wherein said flux absorbing means comprises means for creating eddy currents to reduce the leakage electromagnetic flux.

3. A resolver according to any preceding claim, wherein said flux absorbing means comprises a first flux absorbing element of material selected to create eddy currents therein when exposed to electromagnetic flux.

4. A resolver according to Claim 3, wherein said element is of copper.

5. A resolver according any preceding claim, wherein the rotary transformer comprises a first winding carried by said housing and a second winding on said rotor and operatively associated with said first winding;

   the resolver further comprising means for supplying electrical excitation to said transformer first winding;

   a resolver stator winding carried by said housing and a resolver rotor winding on said rotor and operatively associated with said resolver stator winding; and

   means for obtaining electrical output from said resolver stator winding.

6. A resolver according to claim 5, wherein said element is located between said first winding of said rotary transformer and said resolver stator winding.

7. A resolver according to any of Claims 3 to 6, further including a second flux absorbing element in spaced relation to said first flux absorbing element.

8. A resolver according to Claim 7, wherein said second element comprises an element of material selected to absorb stray electromagnetic flux.

9. A resolver according to Claim 7 or Claim 8, wherein said additional flux absorbing element is of ferromagnetic material.

10. A resolver according to any of Claims 7 to 9, wherein said flux absorbing elements are disposed substantially parallel to each other and substantially perpendicular to the direction of the leakage electromagnetic flux.

11. A resolver according to any of Claims 7 to 10 as dependent directly or indirectly on Claim 5 or Claim 6, wherein said flux absorbing elements are located in spaced relation between said first winding of said rotary transformer and said resolver stator winding.

12. A resolver according to Claim 10 or Claim 11 as dependent directly or indirectly on Claim 5 or Claim 6, wherein said additional flux absorbing element is located between said first flux absorbing element and said resolver stator winding.

13. A resolver according to any of Claims 3 to 12, wherein at least one, preferably both (if fitted), of said elements is/are in the form of a ring disposed in a plane substantially normal to the direction of the leakage electromagnetic flux.

14. A resolver according to Claim 1 or Claim 2, wherein said flux absorbing means comprises:

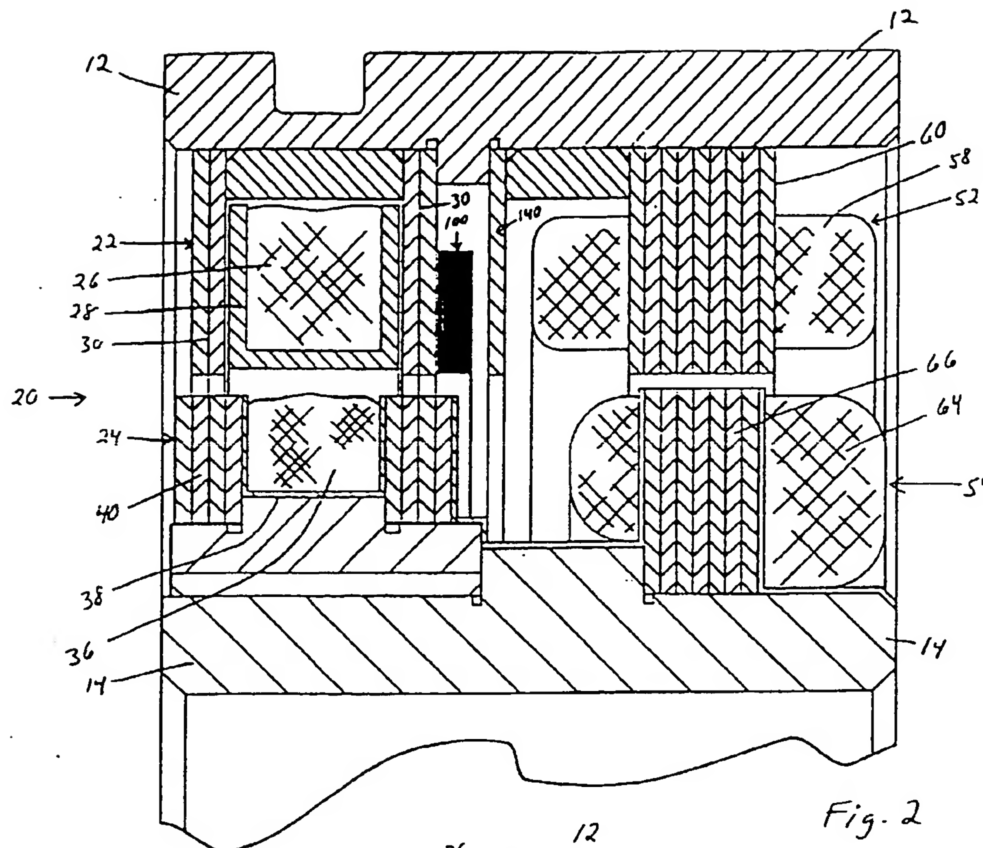
    a) first means for absorbing a principal component of the leakage electromagnetic flux; and

    b) second means for absorbing an additional component of the leakage electromagnetic flux.

15. A resolver according to any of Claims 3 to 13 wherein said first flux absorbing element is adapted to ab-

sorb a principal component of the leakage electromagnetic flux; and

said additional flux absorbing element, where fitted, is adapted to absorb an additional component of the leakage electromagnetic flux.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12
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52
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140
66
64
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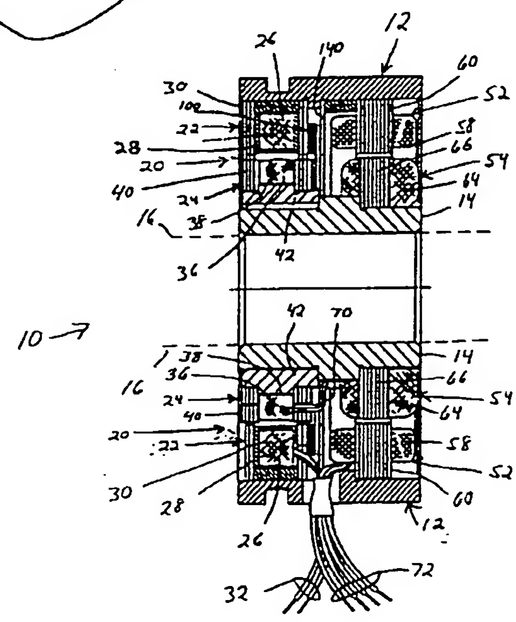
14

Fig. 2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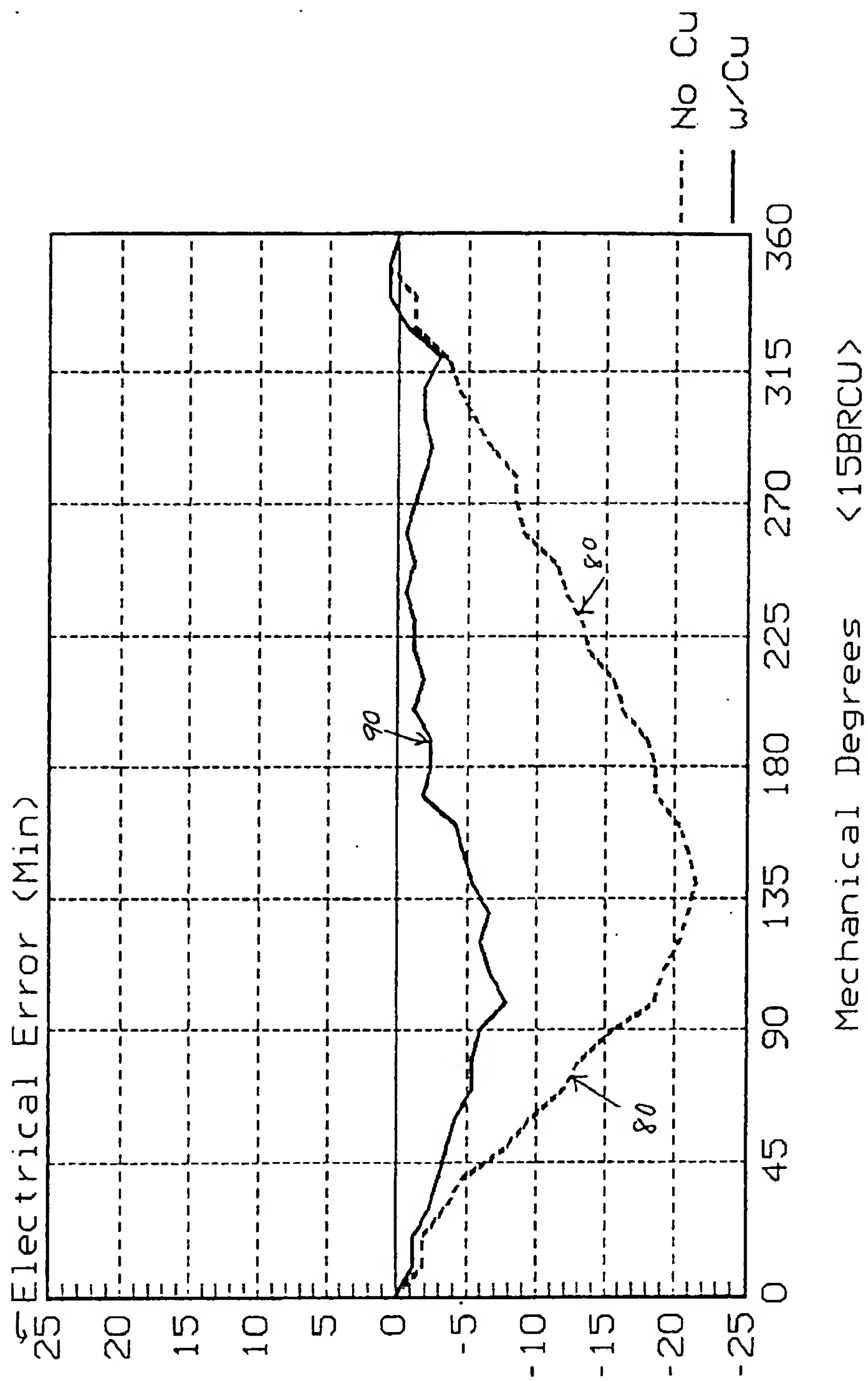
12
30
28
26
32
72

Fig. 1


Electrical Error (Min)
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20
15
10
5
0
-5
-10
-15
-20
-25
0
45
90
135
180
225
270
315
360
Mechanical Degrees
Rotor Revolution
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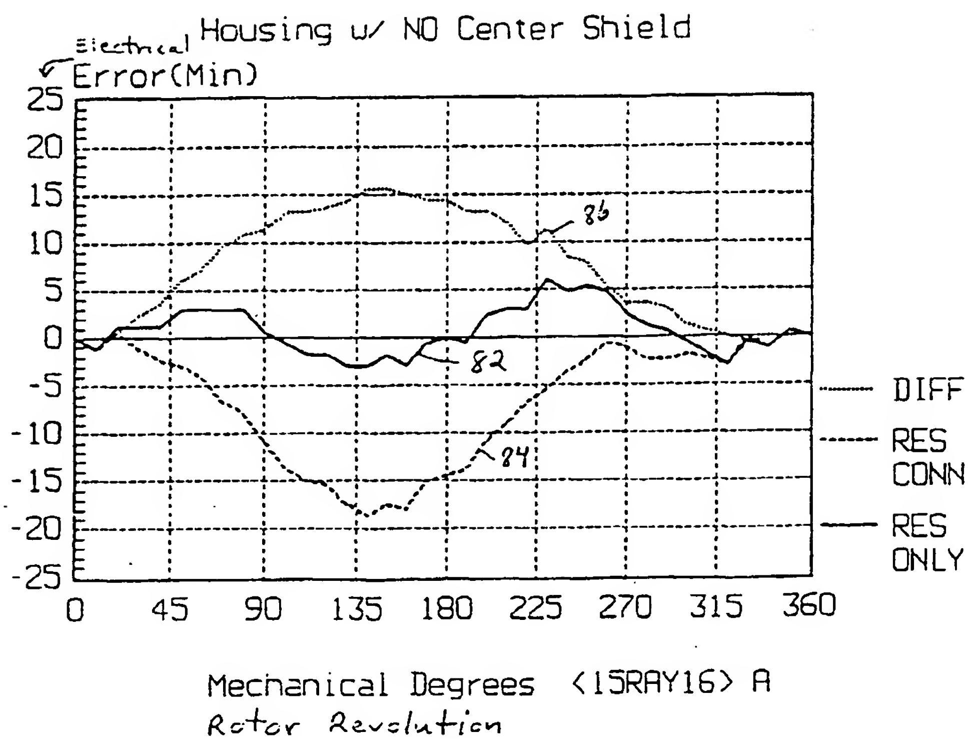
w/Cu
90
80
80

Fig. 3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Electrical Error(Min)
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5
0
-5
-10
-15
-20
-25
0
45
90
135
180
225
270
315
360
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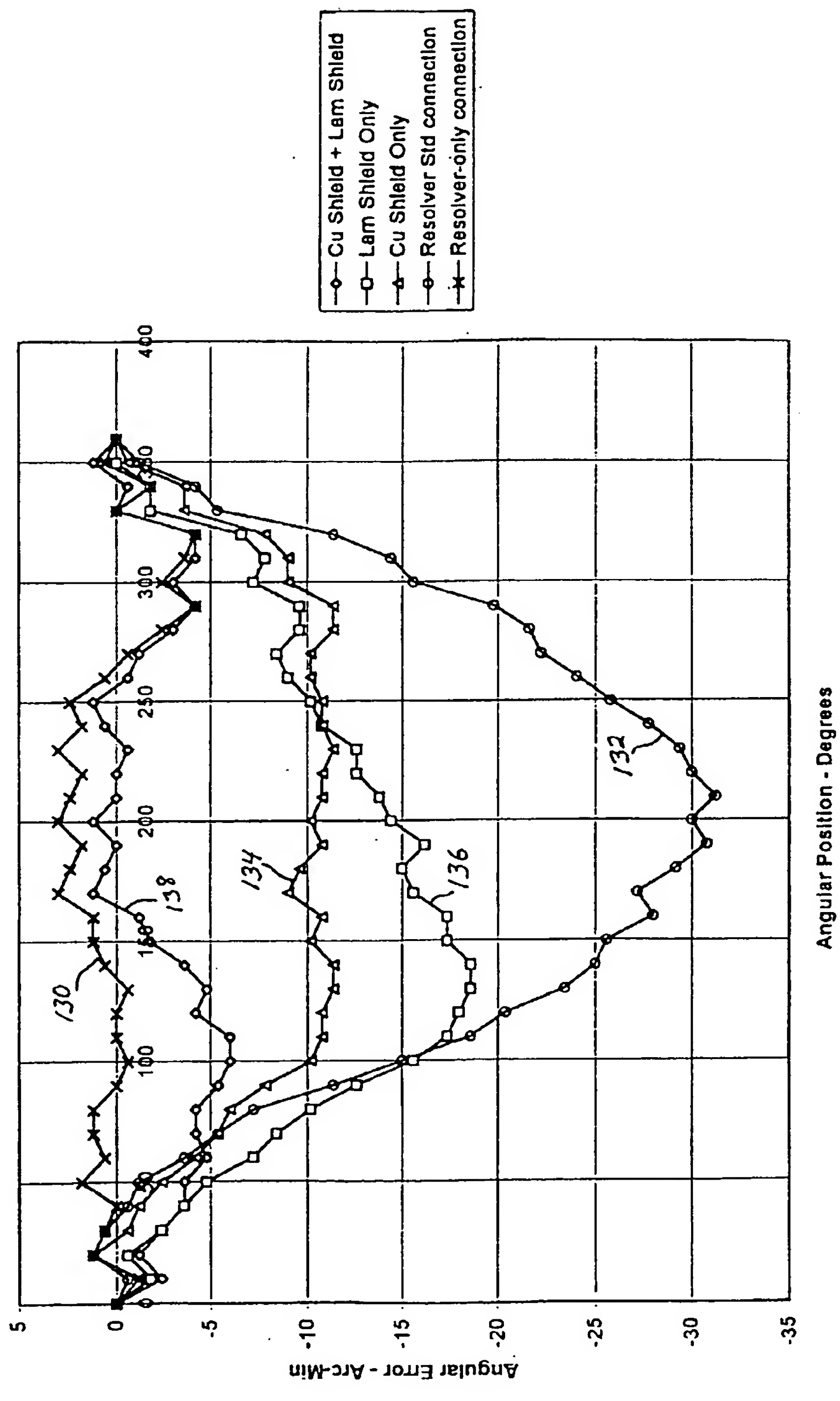
82
84
DIFF
RES CONN
RES ONLY
Mechanical Degrees <15RAY16> A
Rotor Revolution

Fig. 4



Cu Shield + Lam Shield
Lam Shield Only
Cu Shield Only
Resolver Std connection
Resolver-only connection
Angular Error - Arc-Min
Angular Position - Degrees
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0
-5
-10
-15
-20
-25
-30
-35
100
150
200
250
300
400
130
132
134
136
138

Fig. 5

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 30 1680

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	EP 0 593 351 A (GEC ALSTHOM PARVEX SA) 20 April 1994 * column 3, line 28 - column 5, line 8; figures 1-7 *	1-6,13	G01D5/20 H01F38/18
A		10-12, 14,15	

X	DE 42 27 439 A (LITTON PRECISION PROD INT) 24 February 1994 * column 1, line 62 - column 2, line 39; figure *	1-3,5, 14,15	
A		4,6-11, 13	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
H01F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	16 June 1998	Chapple, I

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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